The Qanāt: A multidisciplinary and diachronic approach to the study of groundwater catchment systems in archaeology

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Abstract: The *qanāt*, as a traditional, low-cost, sustainable, water distribution system, was fundamental for the settlement of arid environments. This brief introduction to the special issue ‘‘The *Qanāt*: Archaeology and Environment’’ presents an overview of a workshop of the same name, held at Durham University in October 2014, and introduces the key themes that are explored through the papers in this volume. It also lays out the basis of an interdisciplinary research agenda for *qanāt* studies in archaeology.

Introduction

Subterranean galleries tapping groundwater have been found on almost every continent from South America to western China (Semsar Yazdi and Labbaf Khaneiki: 10-11; Mostafaeipour 2010). These structures bear a different name in each region: *Mina de aqua*, *viajes de agua* and *galería drenante* in Spain, *khattāra* in the mountains of Morocco, *Foggāra* in the Sahara from Algeria to Libya, *qanāt* in the Near East and western/central Iran, *kārēz* in Iraq, Eastern Iran and Pakistan or *Kan'erjing* in China. In Oman and the UAE, the term *falaj* (pl. *aflāj*) is used.

All these structures are adapted to different environments, topographic settings and water resources. Different groundwater sources can be exploited such as watercourse underflows, perched water tables or deep aquifers depending on the context. The length (from tens of meters to several kilometres), the depth (from a few meters to a few hundred meters), and the level of investment necessary to develop these structures are highly variable. However, the purpose of these structures is always the same. They are intended to drain groundwater resources in their upstream section and channel the water to the surface by gravity, the gradient of the underground gallery being lower than that of the natural terrain. They are generally ventilated by shaft holes that are also used to remove the spoil when digging underground.

For the sake of clarity, we have chosen to use the term *Qanāt* in the following discussion when referring to these structures. Not only is it the most widespread, but as recently point out by

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Boucharlat, in Iran, the terms *kārēz* and *qanāts* designate "any type of shafts-and-gallery aqueduct capturing groundwater; thus, these two words should be considered very generic terms" (Boucharlat 2016: 281).

The Durham workshop

This special issue is the end result of a workshop called *The Qanāt: Archaeology and Environment* that was held at the Department of Archaeology, Durham University between October 17th and 19th, 2014. Generous support for the event was provided by the British Institute of Persian Studies, the British Foundation for the Study of Arabia, the British Institute for the Study of Iraq and the Institute of Advanced Study at Durham University. Our aim was to discuss the state of research on *qanāt* technology across the old world (the Middle East and Central Asia, North Africa, and Southern Europe) by bringing together a range of researchers from archaeology, water engineering, geography, and history. The workshop addressed three key themes: methodologies for detecting and investigating *qanāts*; environmental change, sustainability and resilience; and the origins and chronology of *qanāt* technology with a focus on advances in absolute dating techniques.

In recent years, locating and mapping *qanāts* has been aided by the remote sensing of aerial photography and satellite imagery as discussed in papers by Dan Lawrence and Niko Galiatsatos (Durham University), and Louise Rayne (Durham University). Their work illustrated that in combination with historical and environmental data and ground-based survey researchers can better understand the relationship between settlement patterns and *qanāt* systems. Furthermore, remote sensing can be immensely valuable in regions where on the ground access is difficult due to political instabilities.

Recent surveys and excavations of *qanāt* systems in southeast Arabia and Egypt were also discussed in papers by the participants. Carmen Del Cerro (Autonomous University of Madrid) presented the results of excavations by a Spanish team on a *qanāt* (*falaj*) system and associated irrigation network at Al Madam in the UAE. Dave Moger and Derek Kennet (Durham University), working near Rustaq in Oman, discussed their attempts to understand and gather dating evidence for several *qanāt* (*falaj*) systems through the use of the remote sensing of satellite imagery, pedestrian survey, and excavation of *qanāt* mounds. Moving to Egypt, Ahmad Shams (Durham University) focused on a small system in the Sinai Peninsula, which may date back to the Byzantine period, illustrating the adaptation of these systems to mountainous areas. Thierry Gonon (Éveha) highlighted the role of *qanāts* in the colonization of the Western desert of Egypt from the Achaemenid to Roman period.

Shifting to recent work in Iraq, Dale Lightfoot (Oklahoma State University) discussed how important *qanāts* (or *kārēz*) are to Iraq's cultural heritage and how the identification and mapping of now

abandoned *kārēz* can help with their rehabilitation. *Qanāts* were and still area a very important part of Iranian society. This was highlighted by Morteza Fattahi (University of Tehran/Oxford University) who presented an overview of the social and economic importance of the *qanāt* in Iran. Mark Manuel's (Durham University) work also emphasised a clear link between the development of *qanāt* technology and settlement location in ancient Iran.

Broader perspectives on the development of *qanāt* technology and its chronology were presented by Maurits Ertsen (Delft University of Technology) and Peter Magee (Bryn Mawr). Ertsen focused on the technological developments that may have been needed to construct a *qanāt* and how this might influence our thinking about current diffusion models. Magee considered the development of *qanāts* by looking at water exploitation in Arabia over the long-term.

In all cases, the need for obtaining absolute dates for ancient *qanāts* was clear. Ian Bailiff and Lisa Snape-Kennedy (Durham University) directly addressed this through a presentation of their recent work on using OSL (Optically Stimulated Luminescence) to date the construction and use of a *qanāt* system in Spain. This work was contextualised by Chris Gerrard (Durham University) who presented an overview of *qanāt* technology in Spain in long-term perspective. The use of OSL for dating *qanāts* was also explored by Morteza Fattahi (University of Tehran/Oxford University) in his case studies from Iran.

A clear outcome of this workshop was the need for an explicit methodology for investigating *qanāts* in an archaeological context, and the development of a new agenda to guide future research. Furthermore, it was clear that by investigating the role of these systems in past communities, and the relationship between environmental change and human response over the long-term, we could better contribute to discussions about the maintenance and rehabilitation of these systems in a modern context.

State of the Art: discussing the origin and diffusion of* qanāt *technology

Since the beginning of the 20th century AD, *qanāts* have attracted the attention of western scholars. Hogarth (1904) was the first to publish a theory of the origin of *qanāt*, stating that this technology was originally developed in Achaemenid Persia in the 6th century BC. This theory continued to prove popular throughout the first half of the 20th century and was reiterated by English (1968) who proposed the first model of *qanāt* diffusion. He suggested that the spread of this technology went hand in hand with the expansion of the Persian Empires. The impact of this theory continued to influence scholars through the 1970s and 80s. The two most notable publications from this period are J.C. Wilkinson's *Water and Tribal Settlement in South-East Arabia, a study of the Aflāj of Oman* (1977) and H. Goblot's *Les qanats, une technique d'acquisition de l'eau* (1979). In his book,

Wilkinson also defended the theory of an Iranian origin for *qanāt* technology and suggested that it arrived in the region with Persian colonizers with the Sasanian empire (3rd – 7th Century AD) (Wilkinson 1977). Later, Wilkinson (1983: 189) would attribute the implementation of *qanāts* in Oman to local Iron Age populations under the influence of the Achaemenid empire (6th Century BC). Goblot (1979) dedicated an entire book to the topic of *qanāt* in Iran and suggested that roots of *qanāt* construction was to be found in mining technology; he dated this development to sometime in the early first millennium BC. According to him, water drainage from mines was sometimes a necessity and would have inspired the development of the *qanāt*. The cradle of this technology was proposed to be the ancient kingdom of Urartu[3], whose territory corresponds to Eastern Turkey, Armenia and Western Iran (Goblot 1979: 59-68). Goblot (1979: 101) attributed the diffusion of *qanāts*, including their spread to Oman, to the Achaemenids thanks to their territorial expansion. Goblot's book had a great impact on subsequent *qanāt* literature. His assumptions, including the theory of a mining origin for *qanāts* and the dissemination of the technology by Achaemenids, remain commonly cited (see, among others, Hodge 2000: 35-38; Lightfoot 2000; Mostafaeipour 2010: 61 and 65).

Some scholars have, however, questioned the model of diffusion driven by imperial expansion, but continued to advocate for an Iranian origin. Potts, for example, has suggested based on evidence supporting a pre-Achaemenid date for several *qanāts* in Oman that "[t]hus conceivably, the *falaj* of Oman pre-dated the Achaemenid period by several centuries. Their introduction may have been part of the same processes of contact with the Iranian side of the Gulf which account for the marked similarity between certain Iranian and Omani pottery and metal types…" (Potts 1990: 392).

The theory of a Persian origin of the *qanāt* was partly grounded in the belief that this advanced technology could only have been developed by a 'complex' civilization such as Ancient Persia. For instance, J.C. Wilkinson (1977) assumed that the tribal structure of Omani society prevented the digging of new *aflāj*; populations of Southeast Arabia had only maintained preexisting structures that went back to Persian times. Furthermore, as Boucharlat (2016: 294) has recently observed, there were several other facts that were commonly seen as lending support to this theory. This included the fact that Iran boasts more *qanāts* than any other region of the world, and that a text by Polybius, written in the 2nd century BC, refers to some sort of underground aqueduct ventilated by shafts. This interpretation has been highly-debated and the structure may or may not be a *qanāt*[4]. These early theories regarding the date and geographical origin of *qanāt* technology were all put forward by historians, geographers and engineers and none were grounded on physical evidence from actual ancient *qanāts*.

[3] Goblot based his assumption on the fact that *qanāts* had been initially reported in the region of Lake Van, the heart of Urartian kingdom, by a German scholar (Haupt Lehmann 1926). This was later negated by A. Salvini (2001).
[4] This text has been commented and criticized by P. Briant (2001).

Indeed, there are a number of recent studies that have provided evidence for this technology being more ancient than previously thought, and uniquely adapted to many diverse environments. Early examples of *qanāt* systems are now attested in Southeast Arabia, Egypt and Libya and recent investigations in Iran seem to also point to their early use. *Aflāj* dating back from the Iron Age (1300-300 B.C.) have now been excavated in the U.A.E., in the area of al-Ain oasis (Hili and Bida Bint' Sa'ud, see al-Tikriti 2002) and Al Madam (Córdoba 2013, Del Cerro and Córdoba this volume). However, issues still exist regarding the dating of some of these structures (Charbonnier 2015). Although the evidence is limited, it is regularly stated that Southeastern protohistoric *aflāj* were draining shallow groundwater (Boucharlat 2016: 282-286, Del Cerro and Córdoba this volume). Ancient *qanāts* are also attested in Southeastern Egypt, from Achaemenid to the Roman period (Wuttmann 2000, Gonon 2005). The structures investigated at the Kharga oasis are relatively short in length (a few hundred meters) and appear to have been taking advantage of perched water tables recharged from below by the artesian pressure of the Nubian Sandstone aquifer (Crépy and Callot 2016: 327). In the region of Fazzan, Southwestern Libya, the most ancient *qanāts* are associated with the Garamantian civilization, and have been dated from the 2nd half of the 1st Millennium BC-beginning of the 1st Millennium AD (Wilson and Mattingly 2003: 261-265). In Iran, no *qanāts* have been fully excavated, but archaeological surveys advocate for their implementation during the 1st Millennium BC (Manuel et al. this volume) and OSL dating may even point toward their early development in the Bronze Age (Fattahi 2015).

New theories, Old Problems

The evidence allows us to advocate for a polycentric origin of *qanāt* technology. This theory has been notably suggested by Boucharlat, Yazdi and Khaneiki (Boucharlat 2016: 280; Yazdi and Khaneiki 2017: 9). It is grounded in the fact that the civilizations in which early examples of *qanāts* are attested did not have cultural ties. Furthermore, these geographically diverse examples tap very different sources of groundwater and therefore appear to be specifically adapted to their local environments. Therefore, it seems that this technology developed in different places and times.

However, while we would argue that the evidence against a single origin model is compelling, we still more often than not, lack absolute dates for the construction of individual *qanāts* and systems. In particular, while we can propose relative dates for systems based on their relationship to other landscape features, survey alone is not adequate. Furthermore, without excavations of particular *qanāts*, it is difficult to connect these structures with their contemporary environments or comment on use, or periods of disuse, over the *longue durée*. The cultural and archaeological context of the oldest dated *qanāt* in Iran (Fattahi 2015) is for instance unknown.

Qanāt studies have traditionally been undertaken under the umbrella of history, sociology and agronomy, though more focus has been placed on these features in archaeology over the last 30 years. Despite this, an archaeology of *qanāts* and related systems has yet to develop in the discipline. Such a development is crucial for furthering our understanding, not only of the early development of these water extraction systems, but also their relationship to human settlement in arid and semi-arid regions. With this special issue, we hope to contribute towards developing *qanāt* studies as a specialized area of archaeological research that will benefit from a multi-strand approach involving survey, excavation, geoarchaeology, ethnoarchaeology and absolute dating techniques. Furthermore, we hope to tackle a range of more practical issues such as how we should map, investigate, and date *qanāt* systems, as well as how we should place these results within their social and local geographical context.

Recent research on* qanāts*: themes and the application of new methodologies

The papers in this issue range in geographical scope from Pakistan to Spain, and cover developments from the 1st millennium BC to the present day. Mark Manuel, Dale Lightfoot, and Morteza Fattahi discuss the long-term exploitation of water by means of *qanāts*, emphasising how the technology contributed toward the sustainability of settlement away from perennial water sources on the Central Plateau of Iran in antiquity. Furthermore, they illustrate, by drawing on examples of its utilisation and rehabilitation across the Middle East and North Africa, how even today *qanāts* represent one of the most sustainable water supply systems in the world.

Guillaume Charloux, Paul Courbon, Olivier Testa, and Mathieu Thomas describe a multidisciplinary approach to investigating *qanāt* systems in the face of modern urban development. In particular, they illustrate the benefit of using historical aerial photography/satellite imagery in combination with speleological investigations. This combination of methodologies has allowed them to determine the depth of several *qanāts*, the nature of the sediment they were constructed in, and the deposition processes that have affected them since they fell into disuse.

Julien Charbonnier explores the ethnoarchaeology of *qanāt* systems through a comparative study of water-sharing practices in the old world. Such approaches can help us think about the pluralistic ways in which ancient *qanāts* could have been used and the complex community interactions that may have been in play.

Ian Bailiff, Nathan Jankowski, Lisa Snape-Kennedy, Chris Gerrard, Alejandra Gutiérrez and Keith Wilkinson review the recent use of OSL and geoarchaeology techniques to date the construction and reuse of *qanāt* systems in Spain and Iran, and set out an agenda for how we can apply these dating methods to optimal advantage and further the development of these techniques.

Often, it can be difficult to associate ancient *qanāts* with either the settlements they served or the fields they irrigated. Carmen Del Cerro and Joaquin Córdoba provide a comprehensive case study of a *qanāt* and the irrigation network that it was a part of. Their excavations have also allowed them to understand the relationship between changes in the local water table and human adaptations to instability in an arid environment.

***Advances in archaeological methodologies for the study of* qanāts**

These papers utilise a range of techniques that can provide us with a multidisciplinary model for studying *qanāts* in an archaeological context. Remote sensing of satellite imagery and aerial photography, and in particular historical datasets such as CORONA, have proved invaluable in locating ancient water management systems that have been irrevocably altered by modern development (particularly agricultural programs) (Ur 2005; Wilkinson and Rayne 2010; Wilkinson et al. 2013), something clearly demonstrated by Charloux et al in this volume. In contrast, the underground network is impossible to map remotely and only through exploration of the subterranean parts of the *qanāt* can the full extent and phases of use be understood (Charloux et al.; Del Cerro and Córdoba this volume). However, strength lies in the use of a combined methodology.

Excavation of the subterranean sections of a *qanāt* are also necessary to understand their construction, how they were adapted in response to local environmental change and to obtain absolute dating evidence (Del Cerro and Cordoba this volume), though even this is not always possible (Charloux et al. this volume). Above ground, the upcast mounds generated from construction and successive clear-outs of sediment can also be utilized to date *qanāts* through OSL. Bailiff et al. (this volume) also stress the need to combine OSL dating with micromorphology in order to 1) better understand the formation processes of the upcast mounds, 2) select more accurately the layers to be dated in the upcast mounds, and 3) assess the effects of later environment processes (pedogenesis and bioturbation) on the selected layers in order to strengthen the provided dating.

Still, we need tools with which to interpret the social context of water sharing systems. Direct evidence for how an ancient community may have organized water distribution from *qanāts* is generally lacking, but an investigation of current (and often quickly disappearing) practices can provide us with a range of possibilities (Charbonnier; Manuel et al.; Charloux et al. this volume). Such research offers us a way to think about ancient *qanāts* as living systems reflective of dynamic past societies.

Sustainability and resilience of* qanāts *to environmental change

This increased understanding of ancient and historical *qanāt* systems and their continuously evolving relationship with their local environments over the *longue durée* allows us to link the present to the

past. *Qanāts* are sustainable water extraction systems that do not overexploit the resource (Manuel et al. this volume). They have allowed for the development of new agricultural lands and the continued existence of human settlements for very long periods of time.

Indeed, the role of *qanāts* in the colonization of arid zones, devoid of surface water, has been stressed in several regions in the first millennium BC such as Egypt (Gonon 2005), Southeast Arabia (Del Cerro and Córdoba this volume) and Iran (Manuel et al. this volume). The regions explored in these studies would have remained unsuited to sedentary settlement in the periods concerned without the exploitation of groundwater resources.

Qanāts are a sustainable water technology since, unlike motorized pumps and drilled wells, they only drain the upper part of groundwater or aquifers, allowing them to recharge progressively. Furthermore, *qanāts* are expensive to improve and modify. The lowering of underground galleries necessitates the lowering or displacement of the entire irrigation system. This puts a limit on the extension of these systems. As shown by Manuel et al. and Charbonnier (this volume), *qanāts* are often too expensive to be constructed by an individual and must implemented, and managed, by a group of people. Therefore, they contribute toward the strengthening of social relations in communities, and consequently to the sustainability of the associated settlements.

However, *qanāts* also appear as fragile hydrosystems, sensitive to the abrupt evolution of water resources. Natural hazards, socio-political instability, and technological advances can constitute a threat to these water systems. Modern water pumping has often depleted the aquifers on which *qanāts* rely and have had adverse effects on these systems (Manuel et al. this volume). In Dumat al-Jandal, the introduction of mechanized pumps in the mid-20th century has led to the drying up of *qanāts* (Charloux et al. this volume). Furthermore, the abandonment of the Iron Age *falaj* at Al Madam has been attributed to the lowering of the water table in the context of aridification (Del Cerro and Córdoba this volume). Excavations have shown that populations had to progressively lower the underground gallery and the associated irrigation canals of this *falaj*. Archaeological and historic *qanāts* are therefore excellent proxies for monitoring the evolution of groundwater resources and investigating the human/environment relationship.

Well-studied archaeological examples allow us to link changes in local environments and water resources to the construction, adaption, and even abandonment of *qanāt* systems. This is integral to increasing our understanding of both the fragility and the resilience of this technique (Del Cerro and Córdoba; Charloux et al. this volume). Furthermore, such knowledge can support sustainable water use and contribute to the rejuvenation of *qanāt* systems, which can be built and managed by local

communities, particularly in regions where instabilities are present due to climate and politics (Manuel et al.).

A research agenda for qanāt *studies in archaeology*

The goal of this special issue is to present a new framework for studying *qanāts* in archaeology, one which encourages a rigorous and multidisciplinary approach that utilises the strengths of remote sensing, geoarchaeology, absolute dating methods, and ethnographic and historical studies.

Instead of continuing to debate the origin of *qanāt* technology, despite the lack of reliable dating evidence, it would be more productive to focus on using the tools mentioned above to build up a library of well documented case studies

Spatial archaeology (remote sensing and survey) is necessary to map *qanāt* systems, link them to settlements, and find the location of mother-wells. The cooperation of a geomorphologist is also needed to precisely identify the type of underground water source exploited and to evaluate its evolution. Geoarchaeology is necessary to study sediments in underground galleries and the formation of doughnut-shaped rings around access shafts. Furthermore, absolute dating should be undertaken in coordination with geoarchaeology to identify the precise stratigraphic context of dated samples and their origin. A rigorous approach will help us to better understand the long-term history of water exploitation in diverse regions and expand our understanding of the role of social and environmental factors in the evolution of *qanāts*.

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